Effect of Water and Nitrogen Stresses on Correlation among Winter Wheat Organs

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[1]**Abstract.** Correlation among root, stem, leaf and grain is the basis for the establishment of photosynthate partitioning model, and is of great significance for rational regulation of plant morphology and population structure and improvement of crop economic production. The paper is based on experiment results of dry mater weight of root, stem, leaf, and grain of winter wheat of 5 treatments with different water and fertilizer level, and experiment results of soil moisture and soil nitrogen (NH^{4+}-N 和 NO^{3-}+N). The experiment was carried out in the Farmland Water Cycling Experiment Station of Tianjin Agricultural University in 2008-2009. The relationships between leaf to root ratio, stem to leaf ratio, and grain to stem ratio with root nitrogen uptake was established, respectively. The results indicted that the leaf to root ratio, and stem to leaf ratio was more sensitive to water and nitrogen stresses than that of grain to stem ratio. Both the leaf to root ratio and stem to leaf ratio increased with the root nitrogen uptake, and had positive correlations with root nitrogen uptake with the correlation coefficients above 0.91. The correlation between grain to stem ratio and root nitrogen uptake was not significant within the given range of water and nitrogen stresses. The ratio of grain to stem under water and nitrogen stresses was approximately equal to that without water and nitrogen stresses.

Key words： growth correlation，water and nitrogen stresses, winter wheat, leaf to root ratio, root nitrogen uptake

1 Introduction

Various parts of winter wheat (including root, stem, leaf and grain) integrate to a whole, where each organ has its unique function with close links between different organs. This phenomenon is known as correlation among plant organs (Zhang, 2007). Correlation among root, stem, leaf and grain is the basis for the establishment of photosynthate partitioning model, and is of great significance for rational regulation of plant morphology and population structure and improvement of crop economic production. Davison (1969) republished correlation model between root and shoot in dry matter, the model included nitrogen uptake in previous results. The other previous results presented only correlation models among plant organs and these models are all without both water stress and nutrient stress. For example Michaelis-Menten's formula (Liu, et al. 2010), Thomas, et al. (1997), in additional biomass partitioning indexes (Liu, et al. 2010), or partitioning coefficients (P.M. Driessen, et al. 1997), which imply correlation relationships among plant organs, between crop organs. Based on field experiment results, this paper republished the correlation models between the ratio (the leaf to root ratio, stem to leaf ratio and grain to stem ratio) with nitrogen uptake of winter wheat under water and nitrogen stresses conditions.

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2. Materials and Methods

The experiment of water and fertilizer in winter wheat double factors was carried out at the water cycling experiment bases of Tianjin Agricultural University in 2009. The station located at 116°57'E and 39°08'N, elevation 5.49m, groundwater table 3.70-2.06m. The type of winter wheat is 6001, Growth period was from October 7, 2008 to June 15, 2009. The soil bulk density in 0-100cm is 1.43 g / cm^3. The number of experiment treatments was 11 with 3 replications, and the area of each experiment plot is 66.7 m^2. The dry matter data of roots, stems, leaves, grain, soil moisture and nutrient (include ammonium nitrogen NH_4^+ and nitrate NO_3^+) were measured for all treatments.

These treatments include the combinations of high water (4 times water during all growth period, 60mm each time) and high fertilizer (base fertilizer: 750kg/ha compound fertilizer with potassium sulfate type with 15% nitrogen, 15% phosphorus, 15% potassium, and over 45% total nutrients, topdressing: 225kg/hm^2 urea with 46.2% total nitrogen), medium water (3 times) and medium fertilizer (450kg/ha compound fertilizer, 150kg/ha urea), medium water and low fertilizer (150kg/ha compound fertilizer, 75kg/ hm^2 urea), and without water and fertilizer.

The test depth of soil moisture and nitrogen is 0-160cm which is divided into eight layers, 20cm each layer. From sowing to harvest, eight times was sampled to test nitrogen in indoor method, and soil moisture is tested 22 times using the neutron probe. The root was sampled using root drilling with the inner diameter of 5cm and the drill bit length of 10 cm, cleaned, oven-dried and weighted to obtain the dry weight. Root samples were taken in the ridge and between two ridges, and their mean value is used to calculate the dry weight of the root. Sampling depth is 0-60cm before jointing and 0-100cm after jointing stage, 10cm a layer. Dry matter weight was tested nine times.

3. The Calculation of Nitrogen Uptake by Winter Wheat Root

Nitrogen uptake amount is calculated from the root water uptake multiplied by the soil water nitrogen concentration in different soil layers, which is

$$x(t) = 0.1 \cdot \sum_{i=1}^{t} \sum_{j=1}^{4} S_{ij} \cdot \Delta z_j \cdot C_{ij} / \theta_{ij} \qquad (1)$$

Where $x(t)$ = cumulative nitrogen uptake by crop root from sowing to the day t , kg/hm^2; S_{ij} = root water uptake on day *i* and soil layer *j*, 1/d; C_{ij} = soil nitrogen content (the sum of nitrate and ammonium nitrogen) on day *i* and soil layer *j*, mg/kg; Δz_j = soil depth of layer *j*, cm, and Δz_j = 20cm in this study; i = days number from sowing date, d; j = soil layer numbers, which is j = 1, 2, 3 and 4 for 0-20cm, 20-40, 40-60cm, 60-80cm soil layers, respectively. The root water uptake can be calculated by Equation (2)(Kang, et al. 1994).

$$S_r(z,t) = 2.1565 \cdot T_p(t) \cdot \frac{e^{-1.8z/z_r}}{z_r} \left(\frac{\theta(z,t) - \theta_{wp}}{\theta_{cr} - \theta_{wp}} \right)^{0.6967} \qquad (2)$$

Where $T_p(t)$ = potential crop transpiration rate at time *t*, mm/d ; z = the soil depth from the surface, cm; $\theta(z,t)$ = soil volumetric water content on day t and at depth z, cm^3/cm^3; z_r = crop root depth at time t, cm; θ_{wp} = soil moisture content at the wilting point, cm^3/cm^3; θ_{cr} = critical soil moisture content affecting the root water uptake, cm^3/cm^3. In this $\theta_{cr} = 0.75\theta_f$, where θ_f = soil moisture content at field capacity and θ_f = 36 cm^3/cm^3 within the 0-100cm soil layer. Following Driessen and Konijn (1997), z_r can be approximated by

$$z_r = \begin{cases} 0 & t \le 14 \\ 0.3623t + 1.3768 & 14 < t \le 221 \\ 80 & t > 221 \end{cases} \tag{3}$$

Potential transpiration rate can be expressed as (Kang, et al. 1994),

$$T_p(t) = ET_p(t) \cdot (1 - e^{-K \cdot LAI(t)}) \tag{4}$$

Where $LAI(t)$ = Leaf area index; K = extinction coefficient which is taken as 0.6 in this paper; $ET_p(t)$ = $K_c(t) \cdot ET_o(t)$, $ET_p(t)$ = Crop potential evapotranspiration, mm/d; $ET_o(t)$ = Reference crop evapotranspiration, mm/d, which can be calculated from the Penman-Monteith equation (Richard, et, al. 1998); $K_c(t)$ = crop coefficient. In days without LAI measurement, LAI can be estimated from linear interpolation of two adjacent measurements. $K_c(t)$ can be calculated from (5) (Kang, et al. 1994),

$$K_c(t) = \begin{cases} aLAI(t) + b & LAI(t) < LAI_0 \\ K_{co} & LAI(t) \ge LAI_0 \end{cases} \tag{5}$$

Where *a*, *b*, LAI_0, and K_{co} are constants, which are 0.21, 0.42, 4.2, and 1.30, respectively.

In Eqs. (1) and (2), soil moisture content and soil nitrogen content can be obtained from measured values in the field test. In days without measurement, soil moisture content and soil nitrogen content of different soil layers can be obtained from linear interpolation of measurement. Then the amount of daily root water uptake and nitrogen uptake can be calculated. Using Eq. (1), the cumulative nitrogen uptake of winter wheat can be obtained for different irrigation and fertilization treatments. From Eq.(1), the cumulative nitrogen uptake considers both root water uptake and soil nitrogen content, and can reflects soil moisture and soil nutrient status to some extent. Therefore, cumulative nitrogen uptake can be used for the quantitative representation of nutrient and water stresses effects on plant growth. In this paper, cumulative nitrogen uptake is taken as the moisture-nutrient stresses index to analyze the effect of water and nitrogen stresses on correlation among winter wheat organs, and to establish the relationship between stem to leaf ratio ($K_{sl}(t)$), grain to stem ratio ($K_{s\theta}(t)$), leaf to root ratio ($K_{lr}(t)$) and root nitrogen uptake. The above ratios are defined as $K_{sl}(t) = W_s(t)/W_l(t)$, $K_{\theta s}(t) = W_\theta(t)/W_s(t)$, $K_{lr}(t) = W_l(t)/W_r(t)$, where $W_l(t)$, $W_s(t)$, $W_\theta(t)$ and $W_r(t)$ are dry weights of leaf, stem, ear and root, kg/hm^2. Because the grain test is more difficult, especially before maturity, and ear dry weight test is easier; ear dry weight rather than grain dry weight was used. This is appropriate because the correlation between the maturity grain dry weight and ear dry weight is significant. For example, sampling data on June 15, 2009 resulted in y=0.7872x-117.79, R^2=0.981, where y= grain dry weight, x= ear dry weight, kg/hm^2.

4. Results and Discussion

4.1 Effect of water and nitrogen stresses on winter wheat root water uptake and nitrogen uptake, yield and total dry matter weight

Amount of winter wheat root water uptake and nitrogen uptake are calculated from Eqs (2) and (1) (Table 1) by using 5 treatments. For different treatment, amount of winter wheat root water uptake and nitrogen uptake have great differences, which includes not only the impact of water shortage on the amount of root water uptake, but also the effect on leaf area index difference on winter wheat root water uptake. As can be seen from Figure 2, due to water, nitrogen double stresses, leaf area indexes have greater difference under different treatments. Leaf area indexes of high water high fertilizer and medium water and fertilizer treatments are greater, and their maximum reach 6.53 and 4.96 which appeared in about 0.7 (relative growth period). LAI is smaller for medium water and low fertilizer treatment, and smallest for the medium water and zero fertilizer treatment. Thus, to some extent, root nitrogen uptake amount is a better representation for the degree of water and nitrogen stresses.

Table 1 Amount of winter wheat root water uptake and nitrogen uptake in the whole growing period under different treatments

Treatment	Root water uptake /mm	Root nitrogen uptake /kg/hm^2	Grain yield /t/hm^2	Total dry matter /t/hm^2
High water and high fertilizer	299.4	496.7	6.362	20.355
Medium water and fertilizer	231.8	187.4	6.297	16.245
Medium water and low fertilizer	195.4	95.1	5.522	17.895
Medium water zero fertilizer	166.9	85.5	4.461	14.085
Without water and fertilizer	151.9	67.8	3.491	12.015

4.2 The relationship between leaf to root ratio, stem to leaf ratio, stem to grain ratio and root nitrogen uptake of winter wheat

4.2.1 The relationship between leaf to root ratio and root nitrogen uptake

The relationship between leaf to root ratio and root nitrogen uptake can be expressed as the power function $K_{lr}(t) = ax(t)^b$, where *a* and *b* are two regression coefficients, and the regression results is given in Table 2 using 5 treatments. The regression equations for some testing time do not reach a significant level, but the leaf to root ratio increases with root nitrogen uptake and its power index is around 0.5 with the average value of 0.5460. The coefficient *a* decreases with the relative growth period. By fixing b=0.5, the regression analysis of $K_{lr}(t) = ax(t)^{0.5}$ results in $a = 0.0584t^{-1.9884}$. Using 2 to approximate the power index 1.9884, the relationship between leaf to root ratio and root nitrogen uptake can be expressed by equation (5).

$$K_{lr}(t)=0.0584x(t)^{0.5}\cdot t^{-2} \qquad (5)$$

Table2. Relationships of leaf to root ratio and root nitrogen uptake at different growing period

Time/year-month-day	Growth days	Relative growth period	a	b	Squared correlation coefficient R^2	F（1,2）
2008-12-17	71	0.268	1.3258	0.4164	0.3191	0.937
2009-03-27	171	0.367	0.5652	0.3754	0.3741	1.793
2009-04-16	191	0.488	0.1642	0.4875	0.5933	4.376
2009-05-07	212	0.655	0.0864	0.5658	0.7373	8.420
2009-05-14	219	0.722	0.0990	0.5196	0.7929	11.486
2009-05-21	226	0.789	0.0467	0.6612	0.8591	18.292
2009-05-27	232	0.852	0.0271	0.7575	0.7894	11.245
2009-06-04	240	0.936	0.0645	0.5022	0.5864	4.253
2009-06-15	251	1.055	0.0281	0.6285	0.6702	6.096

Note: significant $F>F_{0.05}=18.5$, not significant $F<F_{0.1}=8.53$.

4.2.2 The relationship between stem to leaf ratio and root nitrogen uptake

The relationship between $K_{slm}(t)/K_{sl}(t)$ and $1/x(t)$ is found to be linear (Fig. 1) , where $K_{slm}(t)$ is the stem to leaf ratio under high water high fertilizer treatment. From the linear regression results, the relationship between stem to leaf ratio and root nitrogen uptake can be expressed as

$$K_{sl}(t)=\frac{K_{slm}(t)}{1.0123-27.496/x(t)} \qquad (6)$$

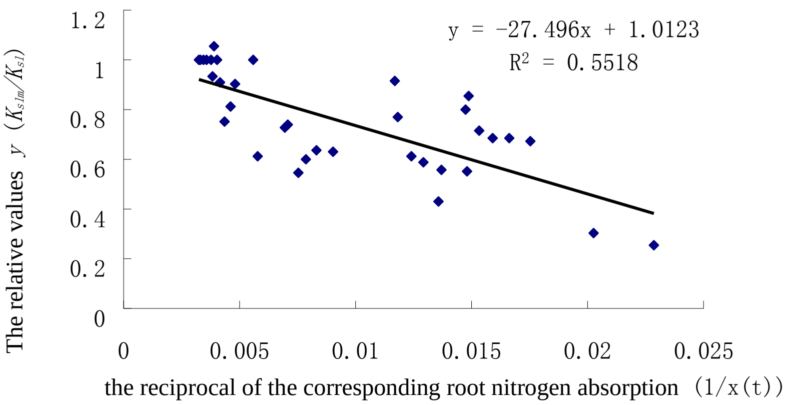

Figure 1 Relationship between stem to leaf ratio and root nitrogen uptake

4.2.3 The relationship between grain to stem ratio and root nitrogen uptake

Relative grain to stem ratio is defined as the grain to stem ratio under varying conditions divided by the ratio under high water and high fertilizer condition. The relationship between relative grain to stem ratio and root nitrogen uptake is shown Fig. 2. As seen from Figure 5, the relative grain to stem ratio ($y_r=K_{\theta s}(t)$) remains constant for different root nitrogen uptake. Linear regression of $y_r=a_2x(t)+b_2$ results in $a_2=-0.00005$, $b_2=0.98$ and the corresponding correlation coefficient $R = 0.0245 < R_{0.05}(2{,}33) = 0.349$. It shows that the effect of water and nitrogen stresses on grain to stem ratio is not significant. For winter wheat, in a certain water and nitrogen stresses range (root nitrogen uptake range in 57-306kg/hm^2), the relative grain to stem ratio is not related to root nitrogen uptake, and the value is 0.98 and very close to 1. It indicates that the grain to stem ratio is not affected by water and nitrogen stresses and its value is equal to grain to stem ratio without water and nitrogen stresses.

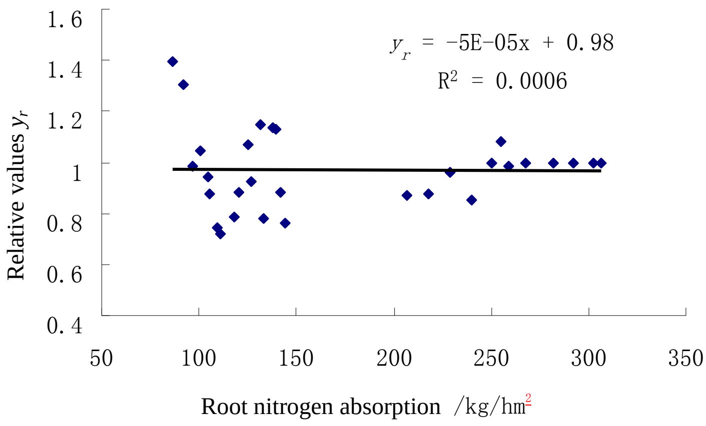

Figure 2 Relationship of grain to stem ratio and root nitrogen uptake

The above results do not mean that grain growth and stem growth were not related to water and nitrogen stresses, and only shown that the ratio of the dry weight of grain to stem did not change or the grain and stem weights increase or decrease in the same degree for winter wheat suffering from water and nitrogen stresses.

In the above analysis, relative ratios with respect to with the high water high fertilization treatment (regarding as no water and nitrogen stresses) were used. As a result, data from different treatment and time can be combined in models, which can be used for correlations analysis of water and nitrogen stresses on the whole growth period of winter wheat.

4.3 Validation

4.3.1 Validation of the relationship between the leaf to root ratio with root nitrogen uptake

Leaf to root ratio can be calculated from Eq.(5) for other different treatments. The scatter plot of measured and calculated values (Fig 3) shown that the scatter points lies around the 1:1 line, with the correlation coefficient $R = 0.9164 > R_{0.01}(2{,}33) = 0.449$ and reached a significant level. This shown that Eq. (5) can be described the relationship between the leaf to root ratio and root nitrogen uptake.

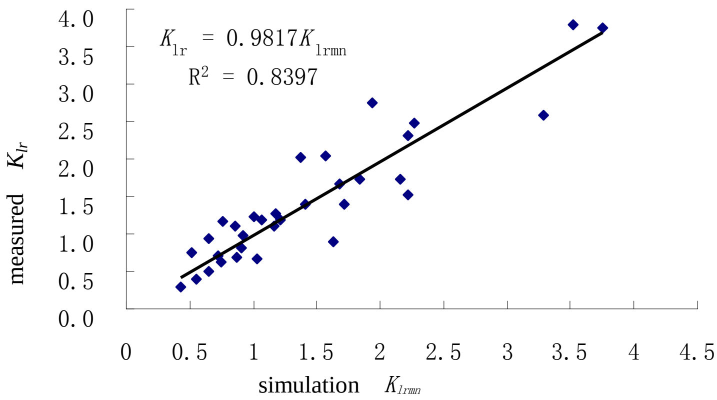

Figure 3 Scatter plot of simulated and measured values of leaf to root ratio

4.3.2 Validation of the relationship between stem to leaf ratio with root nitrogen uptake

Stem to leaf ratio under various root nitrogen uptake conditions can be obtained from Eq. (6). The scatter plot of measured and calculated stem to leaf ratios (Fig 4) shown that the simulated and measured values are close to the 1:1 line with the correlation coefficient $R = 0.9167 > R_{0.01}(2,33) = 0.449$ and reached a very significant level. This shown that the formula (6) expressed the effect of water and nitrogen stresses on stem to leaf ratio of winter wheat. The ratio increases with root nitrogen uptake.

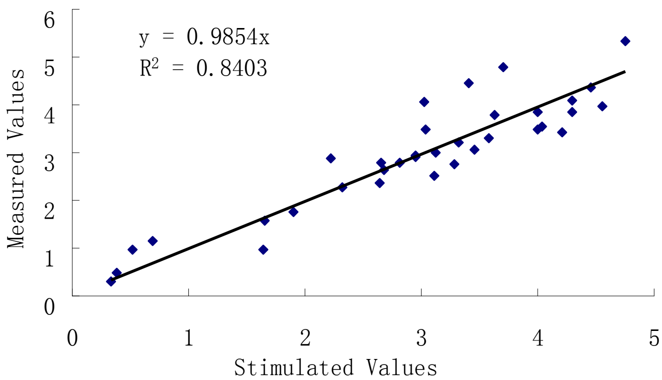

Figure 4 Scatter plot of simulated and measured value of stem to leaf ratio

5. Conclusions

The paper is based on the experiment results of the dry mater weights of root, stem, leaf, grain of winter wheat of 5 treatment with different water and fertilizer levels, and the synchronization testing information of soil moisture and soil nitrogen (NH_4^+-N 和 NO_3^-+N). The experiment was carried out in farmland water cycling experiment bases of Tianjin Agricultural University in 2008-2009. The relationship between leaf to root ratio, stem to leaf ratio, grain to stem ratio and root nitrogen uptake was respectively established. The results show that:

(1) The water and nitrogen uptake by roots, to a certain extent, can be reflected the degree of water and nitrogen stresses and can be taken as the index to describe the effect of water and nitrogen stresses

on crops growth.

(2) Leaf to root ratio and stem to leaf ratio are more sensitive to water and nitrogen stresses than grain to stem ratio, and have significant correlations with root nitrogen uptake, and increase with root nitrogen uptake. For the range of water and nitrogen stresses in this study, grain to stem ratio is not correlated with root nitrogen uptake.

(3) In this paper, the range of water and nitrogen stresses is greater, with the root water uptake varying from 151.9 to 299.4mm, root nitrogen uptake from 67.8 to 496.7 kg/hm^2, and corresponding crop yield from 3.491 to 6.362 t/hm^2, the total dry matter from 12.015 to 20.355 t/hm^2.

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References

1. Xu Ke-zhang, Plant physiology [M]. Beijing: China Agriculture Press, 2007
2. Davidson R I. 1969. Effect of root/leaf temperature differentials on root/shoot ratios in some pasture grasses and clover. Ann Bot. , 33:561-569
3. Liu Tie-mei Xie Guo-sheng, Agricultural System Simulation[M]. Beijing: Science publishers, 2010: 145-148
4. Thomas Kätterer, Henrik Eckersten, Olof Andrén, Roger Pettersson. 1997. Winter wheat biomass and nitrogen dynamics under different fertilization and water regimes: application of a crop growth model[J]. Ecological Modelling, 102: 301-314
5. Shi Jian-zhong Wang Tian-duo，A mechanistic model describing the photosynthate partitioning during vegetative phase [J]，Acta Botanica Sinica, 1994，36（3）：181－189
6. Wang Yang-ren，Water, Heat Transfer and Crop Growth Simulation in SPAC with Water and Nutrient Stress[D]. Northwest A&F University, 2004
7. Richard G Allen, Luis Perein, Dirk Raes Martin Smith, Guidelines for computing crop water requirements FAO Irrigation and Drainage 56, 1998
8. ZhangY-fang, Zhang Wei-zhen, The Present Status of Study on Uptake of Nitrogen by Crop Roots[J]. Irrigation and Drainage, 1996，15（3）：35－39
9. Kang Shao-zhong Liu Xiao-ming Xiong Yun-zhang, Soil-Plant-Atmosphere Continuum Water Transmission Theory and Its Application, Beijing: Hydraulic and Electric Power Press, 1994
10. P.M. Driessen N.T. Konijn write[Netherlands], Yu Zhen-rong, Wang Jian-wu, Qiu Jian-jun et translate, land use system analysis, Beijing: China Agricultural Science and Technology Press, 1997